Patent Application of

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for

Irrigation System Peripheral Communications Using Valve Control Wires

Background of the Invention

This invention relates to automatic irrigation systems, and specifically to a method and apparatus for communication between an irrigation controller and peripheral sensors that provide data to the irrigation controller to assist in the irrigation control process.

Electronic irrigation controllers are commonly used to automatically control irrigation of vegetation such as lawns and gardens in both commercial and residential applications. These systems generally consist of a clock with a mechanism built in for activating an irrigation system at a specified day and time and for a particular duration. Water is applied based on a set schedule, without regard to changing weather conditions. With this type of system it is common to see sprinklers operating during or after a rainstorm when irrigation is unnecessary, and valuable water is being wasted.

Some systems have been enhanced to use various sensors, most commonly soil moisture sensors, to assist in irrigation scheduling. One of the more common embodiments of this type of system uses a conventional timer to schedule irrigation cycles, but will "override" the timer and not allow it to turn on if a certain moisture level is detected in the soil. United States patent 5,148,985 to Bancroft discloses such a system which is applicable to the scope of this patent. When it rains or during cool weather this type of system will tend to water only when needed, thus conserving water.

One drawback of this type of system is that the sensors generally require additional wires to be run to connect them to the controller. The sensors are usually placed in the soil some distance from the controller, which substantially increases the amount of wire required for a system that uses sensors over one that does not. This difference becomes even more pronounced when upgrading a system that has a conventional timer already installed. In most cases this requires trenching in established lawn and garden areas, digging under sidewalks, drilling holes in sides of buildings, etc. to run wires for sensors which causes installation costs to be higher.

United States patent 5,813,606 to Ziff discloses a radio controlled sprinkler control system which overcomes the problems of additional wires required for sensor connection. However, a radio link creates a set of new problems. One of the most significant is the lack of an electrical power connection to the sensors, thus requiring that the sensors use batteries or some other self-powering means which makes this an undesirable choice for many applications.

Most electronically controlled irrigation systems use electric control valves to turn the flow of water on and off. The actuating mechanism contained within the valves generally consists of a wire wound iron core solenoid which is actuated by the magnetic field that is produced when an electric current is applied to the terminals. These solenoids are characterized by a high level of inductance, usually somewhere on the order of 70 to 100 millihenries, which can be used to advantage and provides a key element to the functionality of circuitry used in this invention. The valves are generally installed in the field, near to where moisture or other type sensors may be located. There must be means for an electrical connection between a controller and valves for the controller to initiate action within the valves, which is generally in the form of PVC insulated solid copper wires, which are often called valve control wires. These valve control wires usually contain alternating current when a valve is active, generally at a voltage of 24 VAC.

Using these valve control wires to provide electrical connection to sensors as well as valves, such that a sensor located in the vicinity of the valve could tie into the valve wires, could eliminating the need for separate wires to be run for the sensor and thus save tremendously on installation costs to upgrade existing irrigation systems. However, this presents some difficulties because the voltage to drive the valves is much higher than what is compatible with most types of sensors. Also the valve itself presents a variable load which would cause erroneous readings from most sensors if attached directly to the valve control wires. An additional difficulty is the fact that the irrigation controller usually contains a type of solid state device known as a triac to switch the voltage applied to the valves on and off. One characteristic of triacs is that a rapidly changing voltage applied to one of its terminals can cause the triac to become active or "fire" prematurely. A sensor communicating over a valve wire could cause this to happen if signals to or from the sensor are not carefully controlled. My invention provides a means to overcome these problems and limitations.

Some of the principles used in this invention are similar to those used in prior art for power line networking, such as disclosed in United States patent 6,252,755 to Willer. However, it is my belief that these principles have not been previously applied to the area of irrigation system peripheral communications, and further that this invention provides new and unexpected results of this technology which are not obvious to those not invoking the inventive faculty.

Brief Summary of the Invention

This invention provides for an economical means to upgrade existing conventional timer type irrigation control systems to a system that utilizes moisture and other types of field environment sensors, which can improve irrigation scheduling. Instead of requiring that wires be run the full distance from the sensor to the controller, the sensor is merely connected to nearby valve control wires, eliminating much of the costly trenching required to upgrade a system. Another advantage is that connections are simplified at the controller. There are no additional wires to connect. The sensor signals come in on the

valve control wires that are already present. A timer with a built in sensor interface does not require any additional terminal posts for the sensors. The sensor connections are simply made out in the field at nearby control valve locations.

Additional advantages and novel features of this invention will be set forth in part in the following description, and in part will become apparent to those who are skilled in the art upon examination of the following, or may be learned by practice of this invention. The advantages of this invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

Description of Drawings

Fig 1 is a schematic diagram of an irrigation system using this invention with an active sensor.

Fig 2 is a schematic diagram of an irrigation system using this invention with a passive sensor.

Fig 3 is a schematic diagram of the preferred embodiment of communications filtering and isolation circuitry used in this invention.

Fig 4 is a schematic diagram of an alternative embodiment of the communications filtering and isolation circuitry used in this invention.

Fig 5 is a schematic diagram of the passive sensor filtering and isolation circuitry used in this invention for connecting to a passive sensor.

Detailed Description of the Invention

A typical embodiment of this invention is illustrated in Fig 1. An irrigation controller **10** (such as a Rainbird ISA-406 which is one of a wide variety of controllers commonly available through irrigation equipment dealers) is connected to one or more control valves **12** through valve control wires **11** and **15**. Only one valve is shown for clarity,

additional valves may be connected in a similar fashion. A typical system will have many valves connected to one controller. Valve control wire **11** provides power, usually at 24VAC, to actuate the valve. It is often driven by a solid state switch, known as a triac, from within controller **10**. This switch causes power to be applied to wire **11** when it is time to irrigate, causing the valve to open and allowing irrigation to take place. Valve control wire **15** is the valve common connection which provides a return path for the electrical power from the valve. It is usually connected to the common node of the controller power supply. When multiple valves are connected, each valve has one unique power wire **11** to control the valve. A single common wire **15** can be shared between the valves, or each valve can have a unique common.

Out in the field near to a control valve **12**, one or more communications filters **14** are electrically connected to valve control wires **11** and **15**. Active sensor circuitry **13** is electrically connected to filter **14** through signals sensor transmit **23**, sensor receive **24**, and sensor common **25**. Back at or near controller **10**, which is generally some distance from control valves, a similar communications filter **16** is electrically connected to valve control wires **11** and **15**. Sensor data acquisition circuitry **17** is electrically connected to filter **16** through signals data transmit **20**, data receive **21**, and data common **22**. Data acquisition circuitry **17** can communicate digital data with active sensor **13** in a serial half-duplex fashion to obtain environmental data such as soil moisture, temperature, etc. Circuitry **17** can then communicate this sensor data **18** to controller **10** using a variety of methods which one skilled in the art can easily implement. For example, circuitry **17** may send digital sensor data directly to the microprocessor of controller **10** to assist in scheduling irrigation cycles. Another method could involve circuitry **17** controlling a make or break switch on the valve common connection **15** to override irrigation controller **10** when necessary.

Fig 2 discloses an alternative embodiment of this invention, which can be a more cost effective implementation for interfacing with passive resistive type sensors, such as resistive soil moisture sensors. These sensors appear electrically as a simple resistance

which varies with the property being measured. For example, a resistive soil moisture sensor will increase in resistance as the soil dries out. The system of fig 2 is identical to that of fig 1 with the exception that the active sensor **13** and filter **14** are replaced by the passive sensor **30** and passive sensor filter **31**. The resistive element of passive sensor **30** is connected across terminals **32** and **33** of passive filter **31**.

Instead of digital half-duplex serial communications, the system of fig 2 uses an analog stimulus signal sent out by data acquisition circuit **17** through terminal **20** of filter **16** to excite the passive sensor **30**. Circuit **17** then uses an analog to digital converter to sample the analog signal returned from sensor **30** through filters **31** and **16** through terminal **21**. Terminal **22** of filter **16** is again the common connection between filter **16** and data acquisition circuit **17**.

Fig 3 is a schematic diagram illustrating in detail the dual communications filters **14** and **16** of fig 1 and the single communications filter **16** of fig 2 according to a particular embodiment of this invention. Referring to the connection of fig 2, terminal Vpwr is connected to power valve control wire **11**. Terminal Vcom is connected to common valve control wire **15**. Terminal Rx is the data receive signal **21**. Terminal Tx is the data transmit signal **20**. Terminal G is the data common signal **22**. Similar connections are used in fig 1 for both filters **14** and **16**.

Resistor R1 and capacitor C1 form a low pass filter to prevent misfiring of triacs which may be used in controller **10** by filtering high frequency signals which can cause misfiring. Also, for the passive sensor system in fig 2, R1 provides a reference resistor which creates a voltage divider with the resistive sensor and allows the resistance of the sensor to be determined.

Components R2, R3, R4, C2, and C3 provide a high pass filter to isolate sensitive components from potentially harmful 24VAC signals used to drive control valves **12**, which are at a frequency of 50 or 60 Hz. Diode D1 along with resistors R3 and R4

provide overvoltage protection from transient voltage spikes and ac currents, as well as negative voltage protection from the discharge currents of capacitors C2 and C3 so that these filters may be used in single supply systems.

Component values for this embodiment of the present invention shown in fig 3 are as follows: R1 is 1.0 kilo ohms with 1% tolerance. C1 is 1000 pico farads. D1 is a 4.7 volt zener diode. R2 is 10 kilo ohms with 1% tolerance. C2 and C3 are 0.33 micro farads, 50 volt capacitors. The peak voltage of a 24VAC signal can be close to 40 volts, thus a 50 volt rating on the capacitors should be considered a minimum. R3 and R4 are 47 ohms.

Fig 4 is a schematic diagram illustrating in detail an alternative embodiment of dual communications filters **14** and **16.** The circuits of figs 3 and 4 are identical except that in fig 4 the receive terminal has been combined with the transmit terminal so that only four connections are required. This embodiment is easily accommodated by those skilled in the art using modern microprocessor technology, by connecting to a processor pin which has both input and tri-state output functionality.

Fig 5 is a schematic diagram illustrating in detail the passive sensor filter **31** of fig 2 according to a particular embodiment of this invention. Referring to the connections of fig 2, terminal Vpwr is connected to power valve control wire **11**. Terminal Vcom is connected to common valve control wire **15**. Terminals S1 and S2 are connected across variable resistance sensor **30.**

Components C4, C5, and R5 provide a high pass filter to isolate the passive sensor from potentially harmful 24VAC / 50 to 60Hz signals used to drive control valves **12**. D2 and D3 are bi-directional transient voltage suppressors to protect capacitors C4 and C5 from transient voltage spikes, which can occur on the long runs of wire used in an irrigation control system.

Component values for this embodiment of the present invention shown in fig 4 are as follows: C4 and C5 are 0.33 micro farads, 63 volt capacitors. R5 is 10 kilo ohms. D2 and D3 are 51 volt transient voltage suppressors (available from Diodes Inc., Westlake Village, CA part number P6KE51CA).

In the embodiment of fig 1, the active sensor **13** and data acquisition circuit **17** are microprocessor-based devices operating from a single 5 volt supply. In the half-duplex mode of operation the data acquisition circuit **17** acts as master and the sensors **13** act as slaves. The master transmits a query to one of the slaves, which in turn transmits information back to the master. The slaves are set to receive mode while waiting for a transmission from the master by setting the transmit signal to a high impedance state and monitoring the receive signal. When a slave receives a query, it responds by enabling the transmit signal while at the same time the master is put into receive mode. When the slave is finished transmitting, it immediately returns to receive mode to allow the master to resume control of the communication lines.

In the embodiment of fig 1 it is possible for data acquisition circuit **17** to transmit power as well as data signals to active sensors **13**. The sensors can recover dc power from the transmitted ac signals by performing either half or full wave rectification on the signals.

There are a wide variety of serial communication protocols which may be implemented. The determination of protocol is largely dependent on the construction of sensor circuitry **13** and data acquisition circuitry **17**, and is left to the discretion of the system designer who desires to use this invention. Common encoding techniques used by those skilled in the art such as Manchester encoding, which is used in ethernet 10 base-T networking, will provide acceptable performance, however there are some drawbacks to this type of encoding technique as discussed below. One limitation of filters **14** and **16** are that a non-zero signal level applied for a duration of more than approximately 100 micro-seconds will charge filter capacitors C2 and C3 sufficiently such that the sensitivity of the circuit to receive signals will be significantly degraded. This means that a protocol where the

voltage level can remain at a logic '1' for several bit periods, such as with a standard 16C550 compatible uart used in RS-232 communications, is not suitable for this circuit.

In the embodiment of fig 1, given that the inductance associated with most control valves **12** is around 70 to 100 millihenries, it has been found that a signal high pulse width of between 10 and 30 microseconds gives the best results. If using Manchester encoding this translates to a maximum baud rate of 100 KHz. Because of the potential for undesirable radio frequency emissions, combined with the fact that most sensors need transmit only a small amount of data, it is suggested that a slower encoding scheme where only a single bit is transmitted at a time with a delay between each bit be used. This type of encoding has been found to work well and is described as follows:

The data line is normally driven low by the transmitting device. It is set to a high impedance state on the receiving devices. To transmit a zero, the line is driven high for 10 microseconds and then driven low. To transmit a one, the line is driven high for 30 microseconds and then driven low. There is a rest period between each bit transmission where the line remains at a low logic state for 6 milliseconds. At the receiving end, when a rising edge is detected a timer is started. The line is then sampled 20 microseconds after the edge to obtain the bit value, and then again at 40 microseconds to validate that the line went low again. To implement half-duplex communications, when all data bits to query a certain sensor have been transmitted, the master tri-states the transmit line and waits for the sensor which was queried to respond by driving the line. When the sensor is finished transmitting data, it tri-states the transmit line, after which the cycle will repeat. This encoding scheme will give a maximum data transfer rate of about 166 bits/second, which is more than adequate for most irrigation related sensors.

In the embodiment of fig 2 the data acquisition circuit **17** is microprocessor-based, and contains a high speed analog to digital converter and operates from a single 5 volt supply. Circuit **17** sends out a digital pulse of 5 volt magnitude and a duration of 30 microseconds on data transmit line **20** which is connected to the Tx terminal of fig 3.

Throughout the duration of the digital pulse the analog to digital converter takes samples from data receive line **21** which is connected to the Rx terminal of fig 3. Different resistance values at passive sensor **30** will cause different waveforms on data receive line **21** because of the voltage divider set up between R1 of fig 3 and the sensor. The effects of the filter capacitors coupled with the inductance of the control valve **12** solenoid causes some non-linearities and distortion in the received waveforms. Different sensors can be modeled and algorithms developed to convert the waveforms into sensor readings. These algorithms can then be programmed into the microprocessor of data acquisition circuit **17**.

In practice, most environmental conditions which are measured by the passive sensor **30** change very slowly. Therefore the sensor need only be sampled occasionally to maintain accurate environmental data. Usually some averaging is performed on multiple readings to reduce the effect of noise in the system, however even when many readings are averaged it is still necessary to only sample the sensors occasionally, such as once every few seconds. By increasing the time between samples, the radio frequency emissions of the system will be reduced, thereby reducing the likelihood that the system will cause undesirable interference with electronic communications equipment.

While this invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments, but is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.